

OPERATION RESULTS OF DISH-STIRLING SOLAR POWER SYSTEM

Jin-Soo Kim, Yong-Heack Kang, Sang-Nam Lee, Hwan-Ki Yoon, Chang-Kyun Yu, Jong-Kyu Kim, Dok-Ki Jo
New & Renewable Energy Research Dept., KIER (Korea Institute of Energy Research)
71-2 Jang-dong, Yusong-gu
Daejeon 305-343, South Korea
jnskim@kier.re.kr

ABSTRACT

As the final step for developing a small-scale solar thermal power generation technology in Korea, a demonstration project for a dish-Stirling power system has been carried out by KIER. During the two years project period, 10 kW dish-Stirling power system was built in Jinhae city and successful solar operations were demonstrated. The system consists of mechanical part for solar tracking, parabolic dish-type concentrator, a number of mirror facets, Stirling engine generator, and control/monitoring devices. Close analysis of operation results revealed that the minimum DNI value for power generation by the system was around 200 W/m^2 and the efficiency of solar-to-power conversion reached over 19 % at above 400 W/m^2 DNI condition. In this paper an example of typical clear day operation and analysis results were introduced.

1. INTRODUCTION

Since the early of 1990s KIER(Korea Institute of Energy Research) has been carried out high-temperature solar researches targeting solar thermal power generation¹. For a successful solar thermal power generation, achieving high-flux concentrated solar thermal energy is one of essential technologies. Among various solar concentration methods, different sizes of parabolic dish-type concentrators have been tried to be developed in KIER and recently, a 10 kW dish-Stirling power generation system was developed and successfully demonstrated. The

demonstrated dish-Stirling system is shown in fig. 1. It is located in the energy science park in Jinhae City a south costal city of Korea. The system consists of a number of mirror facets to have totally 42 m^2 of projected reflection area, a solar tracking system, and a 10 kW Stirling engine integrated by a solar receiver and generator. The diameter of the dish concentrator is 9 m and the focal length 5 m.

This paper introduced a brief summery of the system and demonstrative operation results.



Fig. 1: KIER 10 kW Dish-Stirling Power Generation System (Jinhae City, South Korea).

2. STIRLING ENGINE

In order to produce electricity using concentrated solar energy, a proper power cycle which coverts the thermal

energy to mechanical work is necessary. As well known, Stirling engine uses externally supplied thermal energy to make a mechanical motion using repeated heating/cooling of working gas like helium or hydrogen in a closed loop. So the engine could run by any sources of thermal energy as long as the energy is properly transferred into the working gas. Owing to this advantage, Stirling engine has been taken much interest from various renewable energy technologies. Additionally, the engine is known to make relatively low noise compared to the internal combustion engines and also more environmentally friendly in terms of air pollution. Solar application of Stirling engine, especially for a small-scale dish-type power system, is one of promising applications which is already in a commercial stage through over 20 years of R&D efforts². The engine integrated in KIER's solar power system was supplied by Solo GmbH, Germany and the solar unit of the engine was already proven to be successfully operated with various EuroDish systems in different locations³. A brief summary about the engine specification is given in Table 1.

TABLE 1: SPECIFICATION OF STIRLING ENGINE (V161, Solo GmbH, Germany)

power capacity	0-9.5 kW
max efficiency (heat to electricity)	30 % (15 °C water cooling)
working gas temperature	700 °C
average working gas pressure	3-15 MPa
piston volume	160 cm ³
rotation speed	1800 RPM
working gas	H ₂
built in gas bottle volume	5 liter
lubrication	5W30, 0W40 / 1.7 liter
cooling water volume	10 liter
grid connection	380 V, 3 P, 60 Hz
control system power	24 V
detract power	12 V, air cooling

3. SOLAR POWER GENERATION

In this section, one of clear day operation results was

introduced. Normally in Korea, we don't have many of clear sunny days with high insolation. Hence an example of a full day operation result without hindering by the cloud was selected for a reliable analysis of our dish-Stirling system. Fig. 3 is a snap shot of the system during the operation which was captured through ND filter to see the focus area more clearly. Detailed analysis of system operation results are as followings.

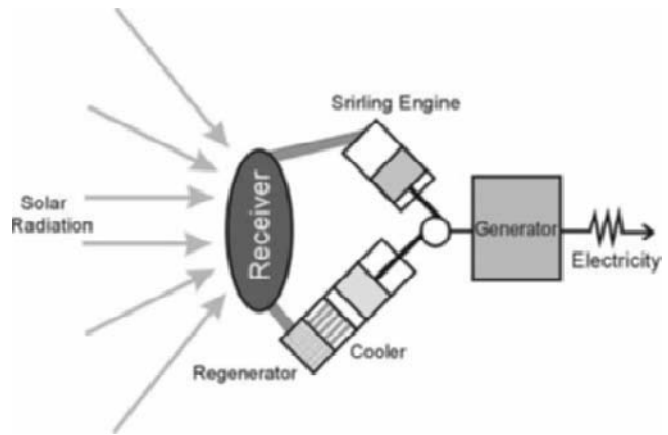


Fig. 2: Scheme of Power Generation Unit with Stirling Engine.



Fig. 3: Dish-Stirling System under Operation (captured through ND filter).

3.1 Operation Results

DNI (direct normal insolation) data during the day of experiment is plotted in fig. 4. The experiment was done in September, 2006 and the data show a typical solar condition of a clear day in autumn of Korea. Maximum DNI value reached over 800 W/m² at around 13:00 and the sunny condition continued until over 18:00. However, due

to a blocking of solar ray by a building nearby, we couldn't have measurements before 8:40 in the morning and the operation of the system was not possible either. Though, around 15:00 in the afternoon, temporary shading happened by the cloud, overall solar condition during the daytime was very good enough to investigate the operation characteristics maintaining stable and reliable running condition.

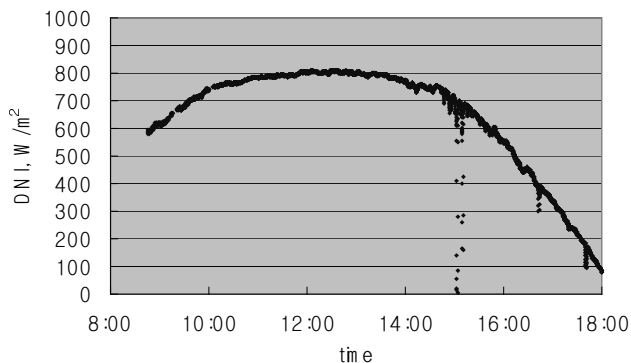


Fig. 4: DNI (direct normal insolation) Values During the Operation.

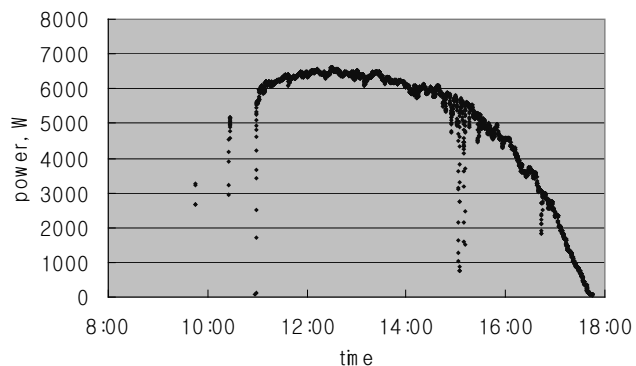


Fig. 5: Power Generation by the System.

Generated power is plotted in fig. 5. The system started running at 9:40 in the morning but it couldn't be operated continuously due to a lack of working gas. So the system was detracted and working gas filling was done. The system was restarted at 10:30 but again stopped running due to a low working gas pressure again. For a proper running, the engine automatically controls the working gas pressure by detecting the level of heat input. However, if the amount of working gas stored in built-in gas bottle is low, the engine can not maintain proper high pressure which corresponds to high insolation. At the moment, because the external working gas charging cannot be done fully automatically, charging the working gas into the bottle

is only possible step by step supply after repeated short time running of the engine with low thermal input. Hence, a continuous stable operation could be done from 11:00 after two times of temporary solar running and working gas charging from external.

From the figs. 4 and 5, it is found that the power generation was done stably by solar energy and maximum amount of power generated from the system reached 6.5 kW at the highest insolation.

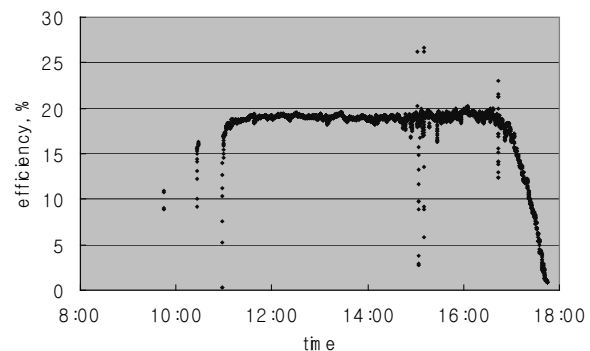


Fig. 6: Efficiency of Solar Power Generation System.

3.2 Performance Analysis

In order to check the performance of our dish-Stirling system, solar-to-electricity efficiency was calculated by the equation (1). In the equation reflection area is a projected area of mirror surface of the dish which is facing the sun and accepting the solar radiation.

$$\text{efficiency} = \left[\frac{\text{generated power}}{\text{DNI} \times \text{projected reflection area}} \right] \times 100 \quad (1)$$

where the generated power is a net power after consuming pump power for the cooling system, DNI values are simultaneously measured ones during the power generation, and the projected reflection area is 42 m².

The calculated system efficiencies are plotted in fig. 6. The figure shows that the efficiency was maintained almost constant around 19 % as long as there is a certain level of DNI available.

In order to see the relation between DNI and power generation, the generated power and calculated efficiency were plotted against DNI value in fig. 7 and 8. From those figures it is found that, in the solar condition over around 400 W/m² of DNI value, the generated power linearly

increases along with the increase of DNI thus the efficiency is almost constant showing around maximum value. In poor solar condition, the efficiency seems to exponentially decrease with the decrease of DNI. It is also found that a minimum solar insolation for an actual power production is around 200 W/m^2 . The average value of efficiency plotted in fig. 8 was 19.2 % when the solar insolation was over 414 W/m^2 . Based on these results, the performance of our dish-Stirling system was characterized by the equation (2) which gives linear relations between DNI and generated power. In the equation two sets of different parameters were determined to give the best regressions in two different DNI regions below and above 414 W/m^2 . Calculated results using equation (2) and parameters are also plotted in fig. 7 as dotted lines.

$$\text{Power} = a + b \times \text{DNI} \quad (2)$$

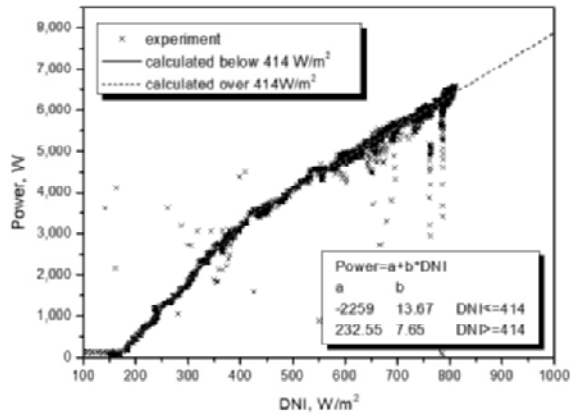


Fig. 7: Power Generation against DNI.

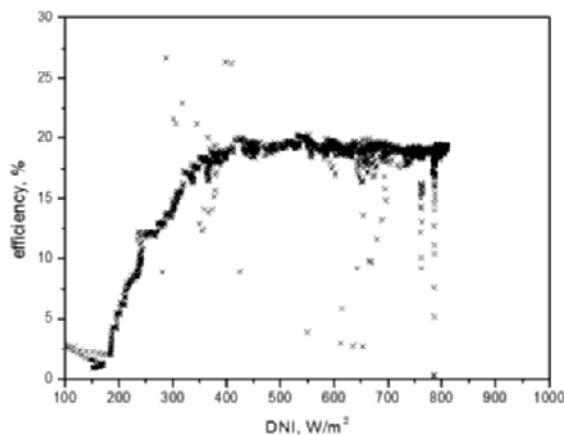


Fig. 8: Power Generation Efficiency against DNI.

where

Power: net power generated, W

DNI: direct normal insolation, W/m^2

$a = -2259$ ($\text{DNI} \leq 414 \text{ W/m}^2$), 232.55 ($\text{DNI} > 414 \text{ W/m}^2$)

$b = 13.67$ ($\text{DNI} \leq 414 \text{ W/m}^2$), 7.65 ($\text{DNI} > 414 \text{ W/m}^2$)

Though this kind of fitting equation does not have a physical meaning of our solar power system, it could be easily used for estimating the amount of power generation after long term operation and for a basic economic assessment of the system.

4. COLCLUSIONS

A dish-Stirling system which was designed for a demonstration of 10 kW solar thermal power generation was successfully built and operated by KIER. The operation results revealed that the system could start electricity production when the DNI is over 200 W/m^2 and with better solar condition over around 400 W/m^2 it could be operated with a high performance over 19 % of solar-to-electricity efficiency.

The Experiences obtained from this demonstration project will be used for modifying the system to be more efficient, reliable and economically competitive, and finally for actual deployment as one of useful renewable energy technologies.

5. REFERENCES

- (1) J.-S. Kim, Y.-H. Kang and, "Progress of R&D Efforts for Solar Thermal Power Generation in South Korea", *SolarPACES 13th International Symposium*, June 20~23 Seville Spain, 2006, IEA SolarPACES.
- (2) W. B. Stine and R. B. Diver, *A Compendium of Solar Dish/Stirling Technology*, 1996, Sandia National Lab.
- (3) A. Ferriere, G. Flamant, J.-M. Gineste, B. Gangnepain, W. Reinalter, P. Heller, T. Keck, W. Schiel. "Lessons Learned from the Experimental Operation of a 10 kW EuroDish Unit", *EuroSun 2006*, June 27-30, 2006, International Solar Energy Society.